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NOTICE

The 13th Annual Open Meeting originally scheduled for September 1945 has been cancelled due to Government restrictions on travel.

Instead, an excellent symposium of papers will be presented by publication in the Institute Spokesman and National Magazines.

DIRECTORS N. L. G. I.

Notes on the Operation and Applications of the S. O. D. Pressure Viscometer

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(Continued from July Issue)

The hydraulic oil which has been suggested for use in the viscometer shows a volume increase of some 10-15% and between 77° and 350° F., and on this basis a correction may be applied to determine the true grease flow rate.

The equipment involved and the methods employed in this temperature range were more fully discussed in a paper "Grease Dropping Point Tests", which was presented at the 11th Annual Meeting of the National Lubricating Grease Institute, November 1, 1943.

C. *Sub-Zero Temperatures*

The S.O.D. Pressure Viscometer may be adapted to low temperature studies in a number of ways, but in so doing there are several factors to be kept in mind. First, the entire hydraulic system, including the Zenith pump, must be enclosed in the bath, since any oil which is sufficiently viscous to prevent pump slippage at room temperature will certainly not flow freely at the lower temperatures. Secondly, if the entire viscometer is to be enclosed in the temperature control unit, the grease in the motor bearings and the oil in the gear reducer will have to be changed in order to obviate excessive running torques at low temperature, resulting in reduced pump speeds and grease flow rates. And third, ample time must be allowed for the grease to reach temperature equilibrium. In an air bath this may require 8 to 10 hours at a bath temperature of, say, −50°F. while in a liquid bath 1 = 1-½ to 2 hours has proved adequate.

The S.O.D. Low Temperature Viscometer uses the liquid bath to obtain the advantage of better heat transfer. Since this made the changing of capillaries difficult, it was necessary to replace the gear reducer with a variable speed transmission in order to cover the desired range of shear rates. Two capillaries of widely different radii and a modified hydraulic system were also required. Since studies on greases at temperatures as low as −70° to −100°F. were desired, a further modification was imposed—the use of shorter capillaries. Arbitrarily, the length-diameter ratio that was decided upon was 12/1. At this stage the viscometer bore little resemblance to the original model, yet it was still a relatively simple and rapid tool and several correlations to service data were attempted and appeared satisfactory. However, when data on this variable flow type of viscometer were compared with those taken with the constant flow model using the standard 40/1 length to diameter capillaries, a wide discrepancy was observed. The curves represented in Figure 4 are typical of this type of variation, where one laboratory used the Precision model in an air bath and the other laboratory used 12/1 capillaries and the variable flow viscometer with a liquid bath.

D. *Errors Involved in the Use of Short Capillaries*

At first glance it was obvious that the gauge pressure used in connection with the low temperature, variable flow apparatus was incorrectly used, or in other words, the pressure drop between the gauge and the capillary entrance was large compared to the drop across the capillary. (Note: The original design, as used by Precision Scientific Company, did not have this characteristic, since 40/1 L/D capillaries were used. However, its limited range for viscous materials or at low temperatures made the use of the shorter capillaries desirable).

Figure 5 indicates the various sources of pressure drop in the liquid bath variable speed drive unit, and these are defined as follows:

p_1 = Hydrostatic head of oil (negligible).
p_2 = Pressure Drop due to viscosity of hydraulic oil (negligible).
p_3 = Piston friction; dependent on temperature (may be considerable at low temperature).
p_4 = Plug flow of grease (should be small).
p_5 = Laminar flow of grease in cylinder + converging to orifices — (Might be large for viscous greases).
p_6 = Capillary End Effects; p_7 = Pressure drop through adaptor to sump (may be large).
p_x = that desired = p_t—(p_1, p_2, p_3, p_4, p_5, p_6, p_7).

The standard model of the S.O.D. Viscometer is designed so that the sum of the pressure drops (p_1, p_2, p_3, p_4, p_5, p_6, p_7, is small compared to p_x at room temperature and for ordinary greases. This is not true at low temperatures, especially where p_x is a function of a capillary of low length to diameter ratio.

The following procedure was used to correct these errors. The two capillaries 0.068 and 0.027" in diameter 12/1), which are normally used in the low temperature tests, were replaced in the present equipment by two which are identical except that they have a 1/1 length to diameter ratio. A series of pressure versus flow rate determinations gave a curve enabling corrections for all of the error producing pressure drops (p_1 to p_7. For example, p_t had been used previously for a given flow rate (Q) to calculate the n& at $4Q/{}^{1T}R^3$ sec. $^{-1}$. The pressure P_a required to cause the same flow (Q) through the 1/1 capillary, when subtracted from p_t gave the true or corrected pressure drop p_e) through an orifice of 11/1 length to diameter ratio: $p_t \div p_t = p_e$.

This correction was applied at both O and +32°F. over a series of flow rates. The corrected values remained some 15-20% higher at 0°F. than the data taken with the longer capillaries, while at +32°F. the agreement was quite good over the entire range. With these corrections the deviations now are of the order of magnitude which can be explained on the basis of previously recognized errors:

(a) differences in temperature
(b) variation with duration of shear. (Short versus long capillaries).
(c) the use of gauge pressures as the true drop across capillaries of 40/1 length to diameter.

Further analysis of these data indicated that p_5, the pressure drop due to the convergence of grease from the cylinder to the capillary was a prime contributor to this error. This led to the belief that some error

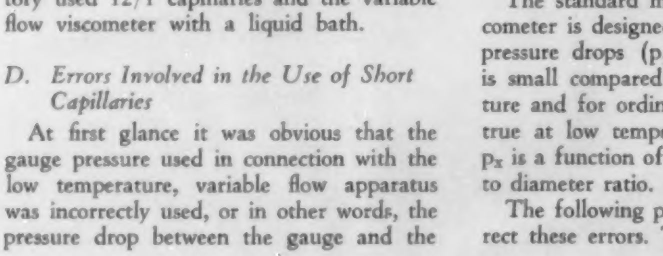
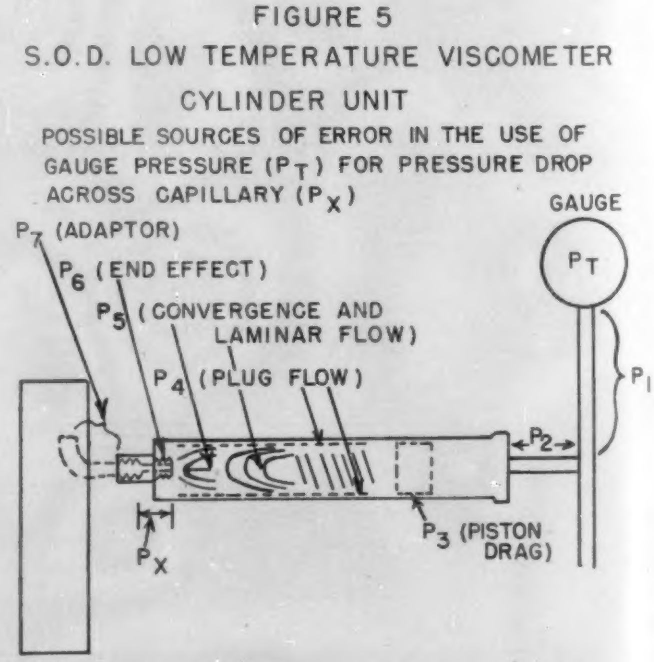


FIGURE 5
S.O.D. LOW TEMPERATURE VISCOMETER
CYLINDER UNIT
POSSIBLE SOURCES OF ERROR IN THE USE OF GAUGE PRESSURE (P_T) FOR PRESSURE DROP ACROSS CAPILLARY (P_X)



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may also be encountered, but to a lesser degree, even with the longer capillaries. When the pressures observed for flow through the capillaries one diameter long were subtracted from those of the 40/1 length to diameter ratio capillaries, the resulting corrected viscosities were some 10-15% less than the original values at corresponding rates of shear. This work was done at 77°F. on two greases of widely different viscosity characteristics. The percentage correction appears to be independent of viscosity. A correction for this error could very easily be applied, but since the test is somewhat empirical it does not seem urgent to do so at 77°F.

The following alternatives and their accompanying requirements, based on what is desired for the viscosity tests, are suggested with the idea of dealing with the wide grease consistency range at both elevated and sub-zero temperatures.

(1) Cooperating laboratories should standardize on one set of capillaries of a given length to diameter ratio to be used at all temperatures and for all greases. This would involve either

(a) a larger length to diameter ratio (~100 to 1) and equipment capable of accommodating pressures from 10 psi. to 20,000 psi., for example, the Arveson type of instrument, or

(b) the use of the present 40/1 length to diameter capillaries and the present equipment, with its inaccuracies at low shear rates for very fluid greases and its limited shear range for viscous greases or at low temperatures.

(2) The use of the present equipment in conjunction with three sets of capillaries, 100 to 1, 40 to 1 and 12 to 1 length to diameter ratios for the three classes of greases over the entire temperature range, accepting the errors involved for the 40 to 1 and 12 to 1 as outlined above and making no attempts to correlate the data from the 3 sets of capillaries.

(3) For special work a correction may be applied as was done in the above treatment.

The problem is not as serious as it may appear, since it seems logical that those greases, which at low temperatures are too viscous to be run in the standard viscometer, are too heavy for most applications. Moreover, it is known that wherever any considerable running torque is involved the lubricant warms up rapidly with a compensating loss of viscosity until the system becomes equilibrated. This leaves only starting torque as a problem, and, since this involves low shear rates, one may still use the long capillaries for the correlations in this region, for at low shear rates the limiting pressures for the viscometer are not exceeded.

IV. Applications—Correlations Between Viscosity and Field Test Data

The grease viscometer finds an important application in classifying lubricants for suitability to a given application, once service data have been made available. There are a number of factors which affect the lubricating properties of a grease that are not revealed by the consistency tests now used for grease specification. While analysis of all these factors is extremely difficult, it is felt that the viscosity-shear diagram gives a sufficiently complete picture, which is a composite of all of these factors. The general principle of all of the correlations is: two or more materials, which possess essentially the same viscosity-shear characteristics at a

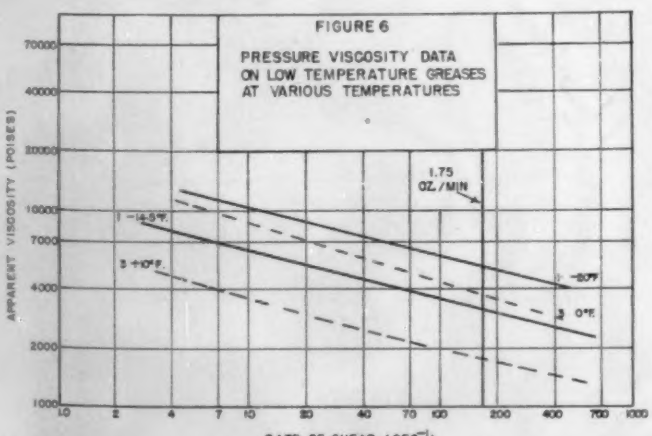
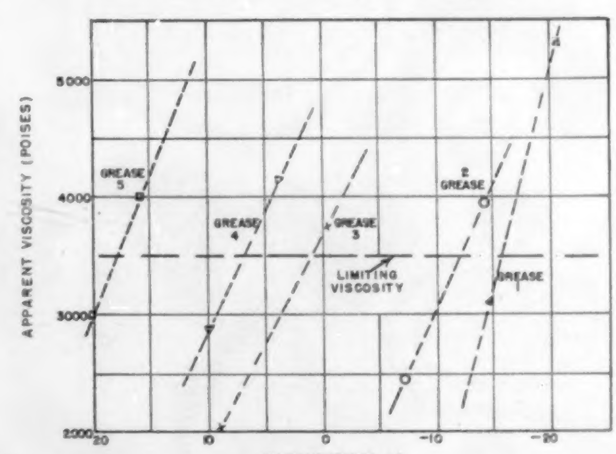


FIGURE 6

PRESSURE VISCOSITY DATA ON LOW TEMPERATURE GREASES AT VARIOUS TEMPERATURES

FIGURE 7

VISCOSITY-TEMPERATURE COEFFICIENTS FOR LOW TEMPERATURE GREASES ESTIMATION OF MINIMUM DISPENSING TEMPERATURES



given temperature, will all perform a particular lubrication service with the same degree of efficiency. The following examples illustrate the general method of correlating viscosity with service data.

Example A—
Consistency Control Specifications

In order to establish a control method for manufacturers, whose intention it is to supply a particular grease, it would only be necessary to stipulate the limiting apparent viscosities for three or four rates of shear, thus roughly defining the entire viscosity-shear curve. The limits would be established on the basis of those materials which have proved satisfactory and unsatisfactory for the particular application. The viscosities, of course, should be determined at the temperature at which the grease is to be used. Moreover, all control viscometers should be of the same design, especially with respect to the capillaries.

Example B—
*Chassis Lubricant Consumption**

The application of viscosity studies to chassis lubricant consumption data has been discussed previously and thus is only outlined here to illustrate the method employed. A number of chassis lubricants were tested for consumption in the shackles of a Buick car equipped with coil spring suspensions, as well as in a simulated service test apparatus consisting of an actuated leaf type spring and shackle assembly from a Chevrolet passenger car. These same greases were studied in the grease viscometer and the data plotted, rate of shear versus shear stress. It was found that the slopes of curves thus obtained (the mobility values) gave a linear correlation with the actual consumption and with that in the laboratory test apparatus. This correlation curve, then, makes possible the estimation of the consumption of a given grease or the life in an actual lubrication test, once the mobility has been measured in the viscometer.

* Previously presented at the November, 1942 meeting of the National Lubricating Grease Institute, New Orleans—"Flow Characteristics of Lubricating Greases."

Example C—
Grease Dispensing Tests at Low Temperatures

In this case the actual service data were obtained on a number of greases of varying composition and over a series of low temperatures, using a power driven dispensing unit of the constant pressure type. Since it was a constant pressure unit, the rate of dispensing decreased rapidly with the temperature. Dispensing rates were recorded at successively lower temperatures until the pump slowed down excessively, or stalled.

The next step was the determination of the apparent viscosities under conditions that would simulate those of the dispensing tests. For this purpose five of the greases were examined at two temperatures in the S.O.D. Low Temperature Viscometer with a capillary of 0.38 cm. inside diameter, approximately the orifice of the dispensing unit.

In Figure 6 the viscosities of two representative greases are plotted against the rate of shear with the corresponding flow rates chosen to overlap the range of questionable dispensing rates in the constant pressure dispenser. Since it was believed that any dispensing rate less than 1.75 oz./min. would make lubrication by this method time consuming, this limit was located on the curve at the corresponding rate of shear, 165 $sec.^{-1}$. The temperatures were chosen to approximate and overlap those giving questionable dispensing rates between 0.75 and 2.5 oz. min. Viscosity values at the intersection of the vertical flow rate reference line were taken off the curves in Figure 6 and plotted against temperature in Figure 7, and here five of the greases are shown to accentuate the variations. As a first approximation 3500 poises was chosen as the limit beyond which satisfactory dispensing would not be obtained and the temperatures at which this viscosity was attained were picked off. These are listed in Table I, column 1. Since the interpolated dispensing rates, column 2, were low for four of the greases the process was repeated for 3000 poises, column 4, and the corresponding dispensing rates listed in column 5. The close agreement between the temperatures in column 3 and 4, where the limiting dispensing temperatures are compared with the temperatures giving rise to 3000 poises, indicates that 3000 poises is a good choice for the viscosity limit. The temperatures listed in column 4 are, then, the minimum useful temperatures for the five greases. There is a slight margin of safety since at these temperatures all greases dispense at least 1.8 oz./min. The test is sensitive to 2° or 3°F., since, for example, at +7°F. Grease IV may be dispensed at only 1.1 oz./min., and similarly for the others where 3°F. can mean as much as 50% decrease in the dispensing rate. Grease I is an exception, probably because of its high viscosity-temperature coefficient, but it is on the safe side.

The test may be further simplified by employing a fixed flow rate viscometer and measuring the temperature at which a given grease exerts a pressure corresponding to 3000 poises under the fixed conditions of capillary size and flow rate. For the capillary used $Kf = 843$; $K_s = 183$ with the 1.75 oz./min. limiting flow rate (165 $sec.^{-1}$), the limiting pressure would be 590 $lbs./in.^2$ gauge. This would be a simple and relatively quickly run laboratory test in comparison to the actual testing in the power driven dispensing unit.

Example D—
Starting and Running Torque Data

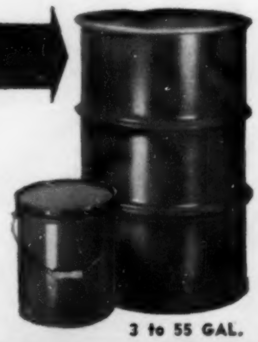
Similar methods were recently employed with data on a series of gear oils involv-

TABLE I

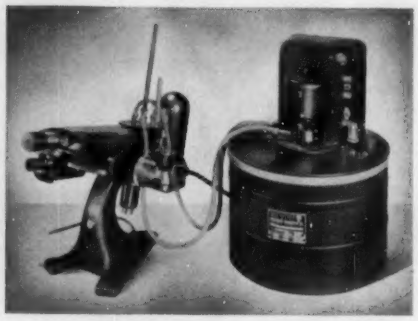
	COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 4	COLUMN 5
Grease	*Temp. °F. Giving 3500 Poises at 1.75 Oz./Min. Flow Rate*	*Flow Rate in Oz./Min. at Temperature Listed in Col. 1*	*Temperature Giving Flow Rate of 1.75 Oz./Min.*	*Temperature °F. Giving 3000 Poises at 1.75 Oz./Min.*	*Flow Rate at Temp. Indicated in Column 4*
I	—15.5°F.	3.0	−17.5	−14.0°F.	4.0
II	−12.0	1.5	−9 to −12	−10.0	2.0-2.5
III	+1.0	1.0	+2 to +4	+3.5	1.8-2.2
IV	+7.0	1.1	+10	+9.5	1.8
V	+18	1.1	+19	+20	2.0

ing torque requirements and forces necessary for meshing and neutralizing the gears in a Chevrolet transmission. By comparing starting torques and shifting data with the gear oil viscosities at low rates of shear and corresponding temperatures, and then slow running torques with correspondingly higher rates of shear a series of limiting viscosities and limiting temperatures were set up which could serve as a means of gear oil specification for low temperature work. The inadequacies of ASTM extrapolated viscosities were also quite evident inasmuch as no correlation was obtainable.

The success of these correlations has proved encouraging and it is felt that the continuation of a program designed to open up new fields of application of the viscometer is well worthwhile. The cooperative program which is now underway, supported by some twenty-five laboratories and the National Lubricating Grease Institute, is certainly a progressive step and the opportunities of such a program should be expedited to the fullest extent.



TESTING ★ TOPICS



SINCE refractive index of many liquids will change as much as 0.005, with a change of 1° C. in temperature, it is imperative that refractometer liquid cell be kept at a constant temperature. The Precision constant temperature circulating system is the first thermostatically controlled, self contained unit to be offered. Can be used also for controlling temperatures of polarimeters, viscosimeters, colorimeters, etc.

The circulating system will operate through a wide range above and below room temperatures. Built-in heater, circulating pump and adjustable thermostat.

After setting the thermo-regulator for desired temperature, the system needs no further attention.

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